CONTRACTOR REPORT

SAND93—7015
Unlimited Release
UC—261

A User's Manual for the Program TRES4: Random Vibration Analysis of Vertical-Axis Wind Turbines in Turbulent Winds

David Malcolm Associates Inc
Mississauga, Ontario, Canada

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of Energy
under Contract DE-AC04-94AL85000

Printed March 1994

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401, FTS 626-8401

Available to the public from
National Technical Information Service
US Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A03
Microfiche copy: A01

Distribution
Category UC-261

SAND93-7015
Unlimited Release
Printed March 1994

A USER'S MANUAL FOR THE PROGRAM TRES4: RANDOM VIBRATION ANALYSIS OF VERTICAL-AXIS WIND TURBINES IN TURBULENT WINDS*

prepared by

David Malcolm Associates Inc
Mississauga, Ontario, Canada

December 1991

ABSTRACT

TRES4 is a software package that works with the MSC/NASTRAN finite element analysis code to conduct random vibration analysis of vertical-axis wind turbines. The loads on the turbine are calculated in the time domain to retain the nonlinearities of stalled aerodynamic loadings. The loads are transformed into modal coordinates to reduce the number of degrees of freedom. Power spectra and cross spectra of the loads are calculated in the modal coordinate system. These loads are written in NASTRAN Bulk Data format to be read and applied in a random vibration analysis by NASTRAN. The resulting response is then transformed back to physical coordinates to facilitate user interpretation.

*The work described in this report was performed for Sandia National Laboratories under Contract No. DE-AC04-76DP00789.

TABLE OF CONTENTS

LIST OF FIGURES

APPENDICES

1. INTRODUCTION

1.1 Background

Vertical axis wind turbines (VAWTs) are machines designed to extract energy from the wind. They differ from horizontal axis wind turbines (HAWTs) in that the structure revolves about an axis that is vertical. One consequence of this arrangement is that under a steady wind the forces experienced by the structure are periodic with frequencies that are multiples of the rotor speed. These cyclic forces give rise to fatigue stresses.

Under non-steady, or turbulent winds, cyclic forces are experienced at frequencies other than the harmonic frequencies. In some circumstances the effect of turbulence on the overall fatigue loading is small, but in other circumstances it has been observed to be considerable. It is, therefore, of importance to be able to predict the structural response under turbulent conditions.

To achieve this goal it is necessary to add considerable complexity to the solution procedure. Not only has the passage of turbulent air to be modeled, but the structural response to (partially) random excitation must be obtained. The first step has been tackled using the method set out by Veers (1984); the second step has been achieved by the use of appropriate MSC/NASTRAN solutions with certain modifications. This manual is concerned with the FORTRAN program TRES4, which prepares the aerodynamic loading for the NASTRAN analysis.

1.2 Objectives

The purpose of this document is, first, to give the reader (who is assumed to have some acquaintance with wind turbine design) some understanding of the basic mathematics. Second, it is intended to give detailed instructions for the use of the program TRES4 and to advise on possible problems.

2. MATHEMATICAL MODEL

2.1 Basic Algorithm

Dynamic structural analysis may be carried out in either the time domain or in the frequency domain. The former involves a step-by-step integration procedure which, for the required number of rotor revolutions (preferably greater than 200), can be very demanding on computer resources and can lead to excessive input and output data. Analysis in the frequency domain is less demanding on data and computation, but both input and output require some interpretation. The second approach has been selected for this procedure.

In order to use the program TRES4 intelligently, some understanding of the basic method is of value. A full review can be found in Malcolm (1988).

If stochastic loads at degrees of freedom a and b are related by cross spectral densities (csd's) $S_{ab}(f)$, then the power spectral density (psd) of the response at degree of freedom i is $S_i(f)$ and is given by

$$S_i(f) = H_{ia}(f)H^*_{ib}(f)S_{ab}(f)$$

where $H_{ia}(f)$ is the frequency response function between degrees of freedom i and a and * indicates the complex conjugate.

In a typical Darrieus rotor finite element model there are about 200 degrees of freedom having aerodynamic loads over a frequency width, which may be discretized into about 100 divisions. The number of terms in the full input would, therefore, be of the order of $2x10^6$. One method of reducing this large file, and the corresponding calculations, is to express the behavior in terms of the modes of natural vibration, thereby reducing the degrees of freedom from 200 to about 20.

The input psd's and csd's can still be very long. Some options exist in TRES4 to help reduce this length by neglecting small values.

MSC/NASTRAN does not normally accept loads as modal components; and it is, therefore, necessary to include modifications (DMAP Alters) to accomplish this.

2. 2 Aerodynamic Model

The aerodynamic model used is the double multiple streamtube (DMST) model (Paraschivoiu, 1984) that has been found to give good predictions of performance without undue computation time. The model carries out an iterative momentum balance calculation at each streamtube into which the swept area is divided at each azimuth position.

In steady winds this calculation need be done for one revolution only. In a turbulent wind it must be done for a number of revolutions so that the full variability of the wind can be represented.

3. ORGANIZATION OF SOLUTION

The total solution procedure consists of five steps.

1. Preparation of MSC/NASTRAN finite element model of rotor and supports.
2. Extraction of real eigenvectors and eigenvalues of the stationary rotor.
3. Use of TRES4 to prepare stochastic aerodynamic loading.
4. Modal frequency response using a suitable NASTRAN solution.
5. Post-processing of output.

3.1 NASTRAN Input File

An example of an MSC/NASTRAN bulk data file is included as Appendix A. It may be prepared in one of a number of ways, although each requires careful evaluation of the structural and inertial properties of the main members.

There is sometimes a choice of ways to model a certain member or feature. TRES4, which reads the NASTRAN bulk file, requires that certain restrictions apply. These are:

- All elements that are to have aerodynamic loads must consist of CBEAM members.

- There is no need to offset the center of mass or center of twist from the grid points.

- The beam members must not be tapered.

- The grid points of the first blade must begin with number 100 (at the top or at the bottom of the rotor) and be numbered consecutively.

- The grid points of the second blade must likewise begin with the number 200.

- Column grid points must have numbers lying between 1 and 99.

- All other grid point numbers (not on the column or blades) must lie above 299.

- To incorporate aerodynamic loading on the central column, the column diameter must be placed in field 10 of the appropriate GRID cards. This field will be read by TRES4 but ignored by NASTRAN.

3.2 Extraction of Real Eigenvectors

The eigenvectors of the stationary rotor are used as generalized coordinates for the aerodynamic loads calculated by TRES4. It is, therefore, necessary to extract these by a suitable NASTRAN solution and to output this information using the PUNCH output option.

MSC/NASTRAN version 66 solutions 3 or 63 or 103 may be used. Appendix B contains sample executive and case control sections for a solution 3 run. The operating system of the computer must be used to ensure that the output is saved under a suitable name.

Appendix A also includes a sample REIG card controlling the extraction of eigenvalues and vectors. It is important that this card and the ASETI cards (for reduction of the dynamic problem) must be the same in this NASTRAN solution as in the subsequent frequency response analyses (see Section 3.4).

3.3 Preparation of Aerodynamic Loads (TRES4)

As Figure 2 indicates, TRES4, which generates the stochastic aerodynamic loads, requires a number of input sources. These are:

- NASTRAN bulk data file (see Section 3.1)
- TRES4 input variables (see Section 4)
- Airfoil data (see Section 6)
- Eigenvectors of the stationary rotor (see Section 3.2)

Figure 2 also shows that TRES4 produces two output files as well as two temporary storage files. One of these (TRES.OUT) contains an echo of the input variables as well as output concerning the variance of the modal loads and output power spectral densities in a format suitable for reading by a post-processing program. The second file (TRESl.OUT) contains data in a format for NASTRAN.

3.4 NASTRAN Frequency Response Analysis

Modal frequency response can be carried out using either solutions 30 (a rigid format solution sequence) or 71 (a superelement solution sequence) or 111 (a "structured" solution sequence). This analysis is complicated by the requirements of including the rotating frame effects, which require an initial solution 64 (geometric nonlinear analysis using at least four subcases) in order to incorporate the stiffening effects of the centrifugal forces. One approach is to pass the data base from solution 64 to the subsequent analysis; since the data bases from structured and unstructured solutions are not compatible, and some changes need to be made to input a data base into a rigid format, the most acceptable choice is the use of solution 71.

Sample executive and case control sections for the combined solution 64 and 71 run are included as Appendix C. Of importance in the solution 64 bulk data is the RFORCE card, which defines the centrifugal loading. The GRAV (gravity) and FORCE (guy cable thrust) should, strictly, also be included, but are probably less significant.

Solution 71 requires the inclusion of a number of modifications. The first is the inclusion of Coriolis and whirling effects. This is done through matrix manipulation (Alter 1087), which relies on basic symmetric and skew symmetric matrices that are defined by DMI cards included at the end of the bulk data file. In addition, the PARAM, OMEGA card must be included to indicate the rotor speed (in radians/s).

Aeroelastic effects on the effective stiffness and damping matrices may also be incorporated as K2PP and B2PP matrices through DMIG cards. If these effects are not included, then it is important to include an estimate of the critical damping of the various modes through a TABDMP1 card, as the example in Appendix D illustrates. This requires a knowledge of the mode shapes of the real eigenvectors and an understanding of what damping to expect in each mode. It has been noted that the blade flatwise symmetric and asymmetric modes experience the most aeroelastic damping.

The consequence of including too little or no damping will be very high response at the natural frequencies of the operating rotor, which will result in overdesign of the rotor components.

3.5 Post-Processing of Results

The output from the NASTRAN random analysis module is in the form of discrete power spectral densities for each selected response. The manner in which these output are requested is illustrated in Appendix C.

Rapid and easy evaluation of results is always important. The designer is interested in knowing the total variance of a particular response and what frequencies dominate this response. The spectra must be extracted from the NASTRAN output by a program designed to read the file or by manual editing. The data may then be plotted by any of a number of commercially available programs. Likewise, the spectra of modal loads included in the file TRES.OUT may be extracted and plotted.

The exact manner in which this post-processing is done will depend on the user's preferences and available hardware and software. It is not, therefore, included with the program TRES4.

4. BASIC INPUT DATA

4.1 Units

TRES4E uses English (imperial) units in contrast to TRES4EM, which uses SI units. The units for the input file variables are given adjacent to the variables as they are described below.

4.2 Format

All comment lines must begin with a '$' in column one (as in NASTRAN). Free format is used except where noted. An example of a basic input file for the 34m Test Bed is included as Appendix F.

4.3 Explanation of Input Variables

Line 1 (free format)

HT	inches	height of rotor between blade intersection points
DIA	inches	maximum diameter of rotor
HMR	inches	mid-rotor height above ground
RPM	rpm	rotor speed
VBAR	mph	mean ambient wind speed at mid-rotor
WSE		exponent defining vertical wind shear
DELT	seconds	time interval in the definition of wind velocity series
ARHO	lb/ft^3	air density

Line 2 (free format)

C1X		coefficients C1 and C2 for use in Frost & Turner's turbulence
C2X		spectrum for X (longitudinal) and Y (lateral) directions
C1Y		
C2Y		
Z0	m	roughness height used in certain expressions for turbulence
DECAY		decay coefficient used to define coherence of cds's of wind velocities. See Veers 1984.
VAR		turbulence intensity of longitudinal wind (standard deviation/mean value). Used in the Kaimal (stable) and the von Karman (neutral) turbulence expressions.
NSOFT		the number of time intervals over which the velocity time series are smoothed. It is recommended that NSOFT=1.
FMIN		an entire csd will be omitted if its variance is below a value equal to FMIN* (minimum of all NEIG psd's)
CMIN		a minimum value of a certain frequency component of a modal load csd below which it will be omitted from the output

Line 3 (free format)

ISPECT	type of formula to be used for atmospheric turbulence (see Section 4.7)

Line 4 (free format)

NHT	number of vertical divisions into which the swept area is divided for definition of wind speed time series
NDIA	number of lateral divisions into which the swept area is divided for definition of wind speed time series. See Section 5.2 for limitations.
NEIG	number of real eigenvectors used as generalized coordinates in modal solution. See Section 5.2 for limitations.
NT	number of intervals per rotor revolution in DMST routine (must be a power of 2). See Section 5.2 for limitations.
NREV	number of rotor revolutions in each analysis. NREV must be a power of 2.
NSECT	number of different sections on each blade corresponding to the number of PBEAM cards required to define the CBEAM blade elements.
NLOOP	number of repeated analyses used to generate an ensemble of load spectra (and correct csd values)
NPMAX	the maximum frequency (in multiples of rotor speed) for analysis and for output
NDIV	number of divisions between per-rev frequencies used in output (NREV must be evenly divisible by NDIV)
NOUT	number of loops after which modal loads will be output to TRES.OUT.
NSUP	number of eigenvectors to be suppressed in NASTRAN analysis. See Sections 4.4 and 4.6.

Lines 5, 6, and 7 (A3 format)

These contain YES/NO requests for upwind and downwind dynamic stall and for use of the ZSET option (see Section 4.4)

Line 8 (free format)

IPRINT	option number for output of csd's. Only option #1 is now valid.

Next NSECT lines (format I4,A8,F10.2)

I		section number corresponding to PBEAM id number (100+I)
TYPE(I)		8-character alphanumeric description of airfoil profile (which must correspond to the description in the airfoil data file - see Section 6)
CH(I)	inches	blade chord

Next 1 up to NEIG lines (free format)

I	eigenvalue number
DAMP(I)	critical damping for mode I. Note that only non-zero values need be given, but that at least one line must be entered.

Next NSUP lines (free format)

I — mode number to be suppressed from the analysis (see Sections 4.4 and 4.6)

4.4 Control of Output

The objective of the analysis is to obtain meaningful results without dealing with excessive input and output. The definition of what is excessive will depend on the particular computing environment. For example, creating the TRES1.OUT file on a PC and sending the NASTRAN input file to another computer via a modem is more restrictive than working directly with a mainframe computer. The maximum size of TRES4 output is also controlled by the present dimension limitations in the program, which is discussed in Section 5.2.

One method of limiting TRES4 output size is to limit the number of eigenvectors (NEIG) used. It has been found that up to about 22 modes is required to allow the modal formulation of a Darrieus rotor to be an acceptable approximation.

Additionally some modes may be suppressed (NSUP > O). An indication of what modes are associated with less load can be found by inspection of the TRES.OUT file. It must be pointed out, however, that due to Coriolis coupling of modes, the lack of a certain modal load does not necessarily imply lack of response in that mode.

The resolution of the power and cross spectral densities submitted to NASTRAN can be controlled. The maximum number of intervals between each per-rev frequency is NREV (which must also be a power of 2). If a larger interval is wanted, then NDIV should be put equal to an integer less than NREV and which is evenly divisible into NREV. For average size rotors, a value of NDIV=16 may be adequate; but for slower rotor speeds, up to NDIV=32 may be desirable.

Many of the csd elements are close to zero owing to the lack of correlation between some modal loads, especially at frequencies that are not rotor speed harmonics. These can be removed from the tabular listing by defining a floor value (CMIN) below which they are omitted. Likewise FMIN controls the floor of the total csd variance below which the entire csd table (or part of it) will be omitted. The FMIN value is the multiple applied to the lowest of the modal load psd variances.

4.5 ZSET Option

The number and location of finite element nodes on the blades is usually governed by structural considerations. For example, nodes may be more closely spaced near the root connections. However, the DMST aerodynamic model may not require the same detail, and much computer time may be wasted in this way.

The ZSET is a subset of the blade finite element nodes that is used in the aerodynamic modeling. It is included in the bulk data file, but is preceded by a '$' so it is ignored by NASTRAN. Following '$ZSET', up to 20 nodes may be listed in format (A5,20I4) as illustrated in Appendix A.

It is recommended that the ZSET not contain fewer than about 16 nodes and that nodes at the intersection of different airfoils and/or chords be included.

4.6 Suppression of Modes

It is sometimes found that a certain high frequency mode is important in the response while some lower frequency modes are relatively unimportant. Exclusion of the latter can shorten the input file and decrease computing time.

Modes can be suppressed by including their total number as NSUP and listing them as described in Section 4.3 and as illustrated in Appendix F.

4.7 Turbulence Models

The variable ISPECT is a number corresponding to the type of formula used for the atmospheric turbulence. This is a subject on which much has been and, no doubt, will be written (see Malcolm 1990).

There are five possible turbulence expressions available within the routine TSPECT of TRES4. They are:

1. Kaimal/Strickland formula (stable atmospheres)
   This is dependent on the overall variance and the C1 and C2 values.
2. Frost & Turner
   This requires Cl, C2 and Z0 values.
3. Kaimal formula (neutral atmospheres)
   This requires C1, C2 and Z0 values.
4. von Karman/Fordham (neutral atmospheres)
   This requires overall variance, Cl and C2 values, and also a measure of turbulence length--at present set at 120 m.
5. von Karman/Fordham (neutral atmospheres and dependent on height and roughness)
   As well as a Z0 value, this expression requires Cl, C2 and a characteristic length, also preset at 120 m.

5. COMPILATION AND RUNNING

5.1 Machine Dependency

The program TRES4E, as listed in Appendix G, has been tailored to run on an IBM-compatible PC using a DOS operation system and a Microsoft FORTRAN compiler (version 4.01 was used). It requires that the machine have at least 640k bytes of random access memory.

The program should run without any changes when later versions of the Microsoft compiler are used. The debug option should not be used since this will result in an executable file which is too large. It is recommended that the program not be run an any PC less powerful than an 80286 with an 80287 coprocessor, or excessive run times will result.

If the program is run on any other machine and/or compiler, some modifications will be required. These changes will principally apply to the input and output, the definition of files, especially the two temporary files (on a machine with more memory these files may be held in RAM if appropriate changes are made to the source code).

5.2 Limitations

Design of the program to run on an IBM PC under DOS led to several limitations in the size of arrays and the corresponding physical phenomena. One array, TRH(128,630), is used to store several variables (time series of velocity perturbations, and the transfer matrix, H, of the matrix, S, of spectral densities). This means that the length of the velocity time series must be less than or equal to 128 values. This, in turn, dictates the time interval if the total time elapsed is to be equal to, say, 16 rotor revolutions. For example, the 34m Test Bed turning at 34 rpm requires a total time of 28.2 seconds for 16 revolutions, which, allowing for some additional time, leads to a maximum time interval of about 0.24 seconds. This, in turn, implies an upper limit of about 2.1 Hz in the turbulence frequency spectrum. While most of the turbulence energy will be within this frequency, it could be undesirably restrictive and, where memory allows, the upper limit could be removed.

The other major limitation arises due to the size of the array of spatial cross spectral densities of wind speed perturbations. The dimension of this array is the total number of spatial points at which the velocity series is defined and the number of spectra is the number of elements in one triangle of this array. Limiting this number to 630 implies representing the flow over the swept area at no more than 35 points (or a 7 x 5 array).

5.3 Linking

The size of the program TRES4 requires that it be divided into two parts in order to compile with a Microsoft compiler on a PC. This can be done by compiling the parts separately and then linking them together.

In addition, the fast Fourier transform routine, FFT842, must be separately compiled and linked with the final executable file. This routine is one of many that will perform the necessary operation, but it is the routine that is called in TRES4.

6. AIRFOIL DATA

All the necessary airfoil data are read in by subroutine READAIR, and a sample of an input file is included as Appendix E. This input file must adhere to the following format restrictions.

1. The file may contain lift and drag coefficients for any number of airfoil shapes, but no more than five can be read by one job.

2. Each airfoil may have coefficients listed at up to five Reynolds numbers.

3. Up to 50 angles of attack may be listed for each set of data.

4. If data at more than one Reynolds number are given for a certain airfoil, then the sets must be placed in order of ascending Reynolds number.

5. The last angle of attack in each set must be 180.0 (exactly).

6. The angles of attack used for different airfoils or for different Reynolds numbers of the same airfoil do not have to be the same (in value or in total number).

7. The file must end with "ENDFILE."

8. Each set or group of data must begin with a line having the eight-character alphanumeric airfoil identifier in the first field (corresponding to the alphanumeric used in the basic input data and described in Section 4.3)

9. The second line of each set contains the following, in (F10.0,2F10.4) format:

RE(i,j)	Reynolds number #j for airfoil #i
AS(i,j)	corresponding static stall angle
CDMIN(i,j)	corresponding drag coefficient at zero angle of attack to be added to all listed values
TC(i)	thickness-to-chord ratio for airfoil #i

10. Subsequent lines contain in 3F10.4 format the following:

A	angle of attack (degrees)
CL	lift coefficient
CD	drag coefficient

7. OUTPUT VIA TRESD.FOR

The program TRES4E can take several hours to run on an 80286 PC when the maximum spatial array is used together with 30 or more ensembles of 16 revolutions each. To avoid having to rerun merely because the variables controlling the TRESl.OUT output are incorrect, the program TRESD.FOR can be used. This program reads the same basic input file as TRES4E.FOR together with the temporary file (TRES2.TMP) that contains the data for the psd and csd's of the output load.

A new set of data in NASTRAN format can be quickly obtained in this way. For example, if the initial settings resulted in the elimination of too many cross spectral densities, then the value of FMIN in the basic input file can be reduced, and TRESD.FOR can be run for a more acceptable set of modal load spectra.

8. AEROELASTIC EFFECTS

The displacements of the wind turbine blades (measured in the rotating frame) cause changes in the angle of attack of the relative wind. This in turn affects the aerodynamic forces experienced by the blades. This interaction between structural dynamics and aerodynamics can be described by classical theories of aeroelasticity and has been investigated by Lobitz and Ashwill (1986), Malcolm (1990), and others.

While there are only small changes on the effective stiffness and mass, the main effect is on the damping matrix. The different modes of response experience different degrees of damping. This damping can be extremely important in attenuating structural response due to stochastic loading at rotor natural frequencies.

Aeroelastic damping can be incorporated in one of two ways. It can be incorporated by estimating (largely by experience) the critical damping factors for each of the real modes and including this information in the basic input file (see Section 4.3), in conjunction with an SDAMP statement in the NASTRAN case control section.

Alternatively these effects can be included in the NASTRAN run by inserting the changes to the matrices as a series of DMIG (Direct Matrix Input - G-set) statements. These lines are generated by running a program called AEROB5.FOR, which is described below.

8.1 Program AEROB5.FOR

This program is fully described and documented in Malcolm (1990). It is based on the work by Lobitz and Ashwill (1986) and predicts the same results (at normal operating speeds). The program requires two input files--one is the same NASTRAN bulk data file as was used in the TRES4 program, and the other is described below.

8.2 Basic Input File

A sample input file is included as Appendix G. The same rules as in the TRES4 input file apply concerning comment lines (they require a "$" in column 1).

Line 1 (free format)

RPM	rpm	rotational speed of rotor
ARHO	lb/ft^3	air density
FLUT	Hz	typical frequency of rotor blades. This is usually set at about 3 times the rotor speed.
AB		fraction of the half-chord by which the center of twist is rear of the half-chord position
CMIN		a minimum value for output values below which they are omitted
NSECT		number of blade sections listed below

Lines 2,3 &4 (A3 format)

"YES"/"NO"	flag for inclusion of rotating frame effects in the calculations
"YES"/"NO"	flag for inclusion of apparent mass terms in output
"YES"/"NO"	flag for use of the ZSET reduced blade node option in place of the full set (see Section 4.5)

Next NSECT lines (format I4,A8,F10.2)

I		section number corresponding to PBEAM id number (100+I)
TYPE(I)		8-character alphanumeric description of airfoil profile (which must correspond to the description in the airfoil data file--see Section 6)
CH(I)	inches	blade chord

9. REFERENCES

P.S. Veers, "Modelling Stochastic Wind Loads on Vertical Axis Wind Turbines," Sandia National Laboratories, SAND83-1909, Sept. 1984.

I. Paraschivoiu, "Aerodynamic Analysis of the Darrieus Rotor Including Secondary Effects," J. of Energy, AIAA 7,(5), pp. 416-422, Sept. 1984.

D.W. Lobitz and T.D. Ashwill, "Aeroelastic Effects in the Structural Dynamics of Vertical Axis Wind Turbines," Sandia National Laboratories report SAND85-0957, April 1986.

P.S. Veers, "Three Dimensional Wind Simulation," Sandia National Laboratories report, SAND88-0152, March 1988.

D.J. Malcolm, "A Model for the Response of Vertical Axis Wind Turbines to Turbulent Flow. Parts 1 and 2", Sandia National Laboratories Contractor's report, SAND88-7021, July 1988.

D.J. Malcolm, "Vertical Axis Wind Turbine Turbulent Response Model," Sandia National Laboratories, Contractor's Report, SAND89-7042, Jan. 1990.

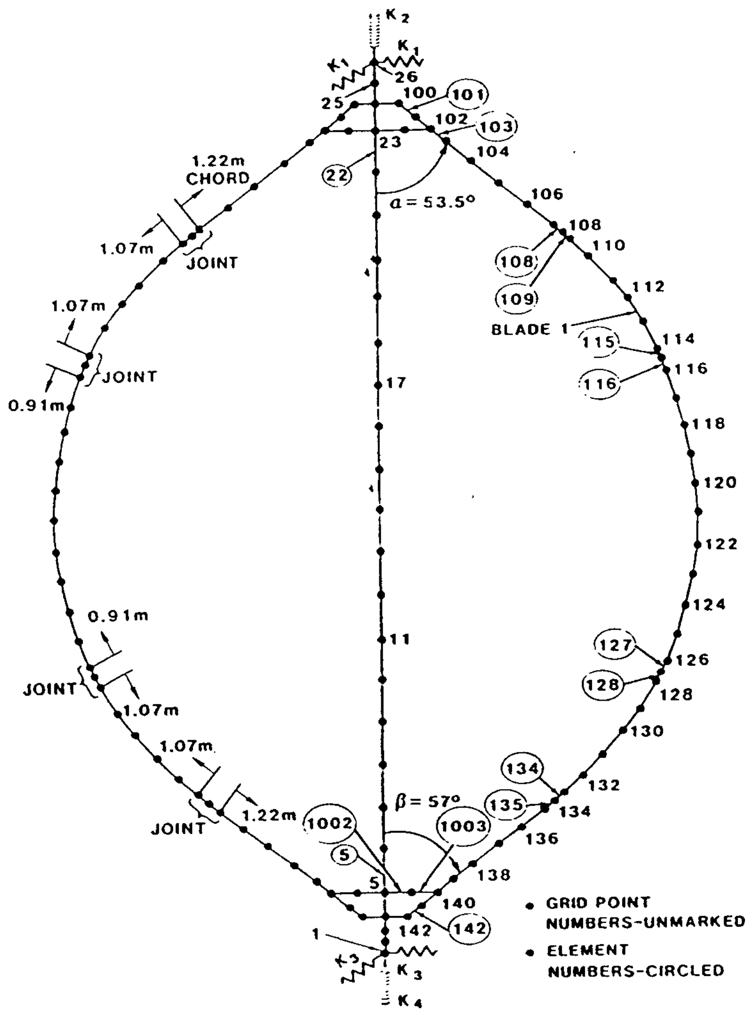

Fig. 1. Finite Element Grid

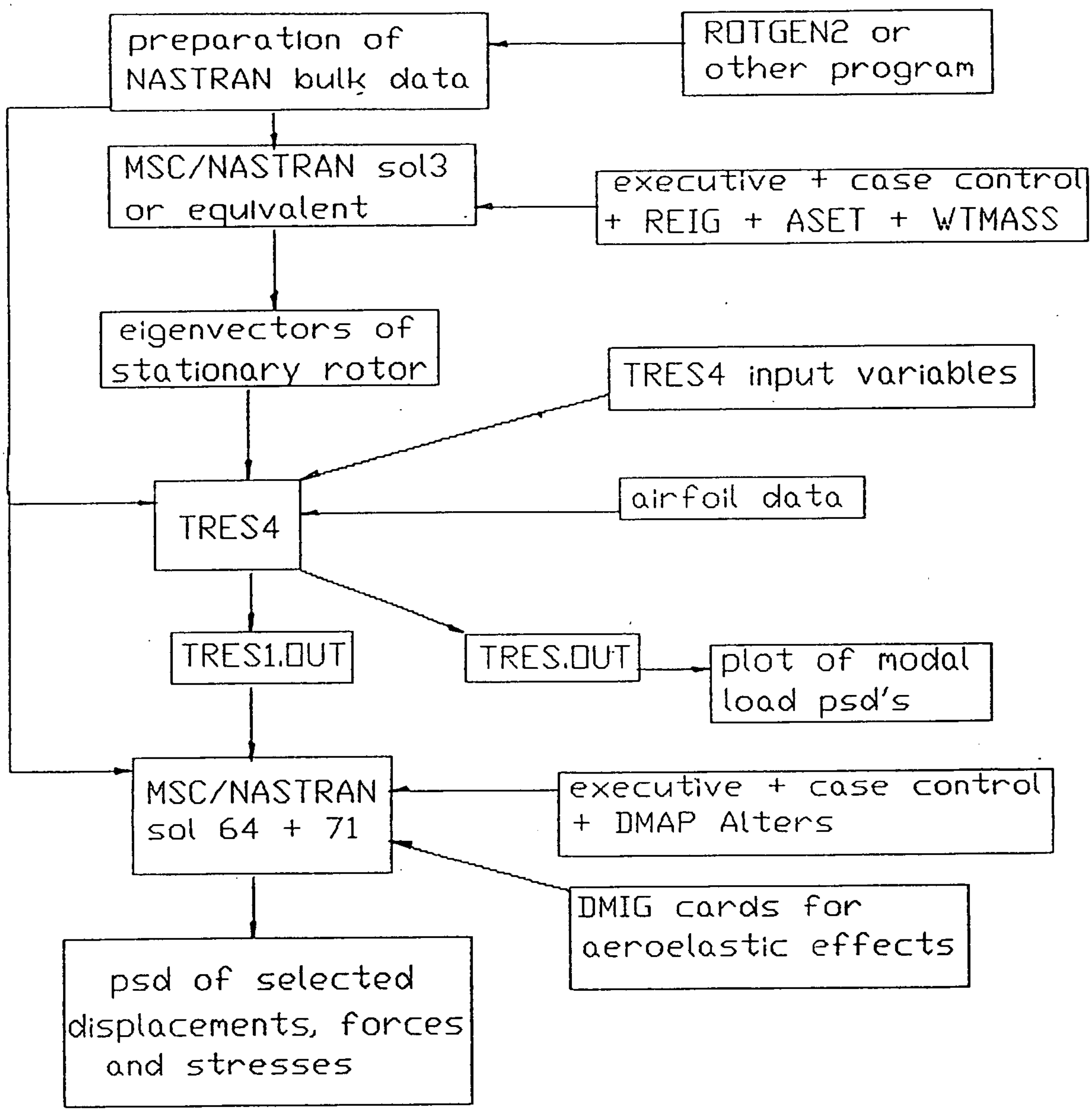

Fig. 2. Schematic of total solution

APPENDIX A

NASTRAN Bulk Data Input File

```
$TITLE=37.5/45 137.5/110 BULK DATA M6T235A W/ AER+AIR //OMG=2.0
BEGIN BULK
$ D MALCOLM VERSION OF ATEST.DAT. MODIFIED TO "11-87 MODEL" MARCH'88
$ PBEAM STRESS RECOVERY MODIFIED 18 MARCH 88. LOCAL COORDS MODIFIED
$ COLUMN CONNECTIONS. SLBULK3-LOCAL COORDS CORRECTED 18 JULY 89.
CBEAM          1      10       1       2    1.00
CBEAM          2      10       2       3    1.00
CBEAM          3      10       3       4    1.00
CBEAM          4      20       4       5    1.00
CBEAM          5      30       5       6    1.00
CBEAM          6      30       6       7    1.00
CBEAM          7      30       7       8    1.00
CBEAM          8      30       8       9    1.00
CBEAM          9      30       9      10    1.00
CBEAM         10      30      10      11    1.00
CBEAM         11      30      11      12    1.00
CBEAM         12      30      12      13    1.00
CBEAM         13      30      13      14    1.00
CBEAM         14      30      14      15    1.00
CBEAM         15      30      15      16    1.00
CBEAM         16      30      16      17    1.00
CBEAM         17      30      17      18    1.00
CBEAM         18      30      18      19    1.00
CBEAM         19      30      19      20    1.00
CBEAM         20      30      20      21    1.00
CBEAM         21      30      21      22    1.00
CBEAM         22      30      22      23    1.00
CBEAM         23      40      23      24    1.00
CBEAM         24      50      24      25    1.00
CBEAM         25      50      25      26    1.00
$ BLADE 1 CONNECTIONS
CBEAM        100      60      24     100    1.00    0.00    1.00
CBEAM        101     101     100     101    1.00    0.00    0.00
CBEAM        102     101     101     102    1.00    0.00    0.00
CBEAM        103     102     102     103    1.00    0.00    0.00
CBEAM        104     103     103     104    1.00    0.00    0.00
CBEAM        105     103     104     105    1.00    0.00    0.00
CBEAM        106     103     105     106    1.00    0.00    0.00
CBEAM        107     103     106     107    1.00    0.00    0.00
CBEAM        108     104     107     108    1.00    0.00    0.00
CBEAM        109     105     108     109    1.00    0.00    0.00
CBEAM        110     106     109     110    1.00    0.00    0.00
CBEAM        111     106     110     111    1.00    0.00    0.00
CBEAM        112     106     111     112    1.00    0.00    0.00
CBEAM        113     106     112     113    1.00    0.00    0.00
CBEAM        114     106     113     114    1.00    0.00    0.00
CBEAM        115     107     114     115    1.00    0.00    0.00
CBEAM        116     108     115     116    1.00    0.00    0.00
CBEAM        117     109     116     117    1.00    0.00    0.00
CBEAM        118     109     117     118    1.00    0.00    0.00
CBEAM        119     109     118     119    1.00    0.00    0.00
CBEAM        120     109     119     120    1.00    0.00    0.00
CBEAM        121     109     120     121    1.00    0.00    0.00
CBEAM        122     109     121     122    1.00    0.00    0.00
CBEAM        123     109     122     123    1.00    0.00    0.00
CBEAM        124     109     123     124    1.00    0.00    0.00
CBEAM        125     109     124     125    1.00    0.00    0.00
CBEAM        126     109     125     126    1.00    0.00    0.00
```

```
CBEAM        127      108      126      127     1.00     0.00     0.00
CBEAM        128      107      127      128     1.00     0.00     0.00
CBEAM        129      106      128      129     1.00     0.00     0.00
CBEAM        130      106      129      130     1.00     0.00     0.00
CBEAM        131      106      130      131     1.00     0.00     0.00
CBEAM        132      106      131      132     1.00     0.00     0.00
CBEAM        133      106      132      133     1.00     0.00     0.00
CBEAM        134      105      133      134     1.00     0.00     0.00
CBEAM        135      104      134      135     1.00     0.00     0.00
CBEAM        136      103      135      136     1.00     0.00     0.00
CBEAM        137      103      136      137     1.00     0.00     0.00
CBEAM        138      103      137      138     1.00     0.00     0.00
CBEAM        139      103      138      139     1.00     0.00     0.00
CBEAM        140      102      139      140     1.00     0.00     0.00
CBEAM        141      101      140      141     1.00     0.00     0.00
CBEAM        142      101      141      142     1.00     0.00     0.00
CBEAM        143       60      142        4     1.00     0.00    -1.00
$ BLADE 1 STRUTS
CBEAM       1000      250       23     1000     1.00     0.00     1.00
CBEAM       1001      260     1000      102     1.00     0.00     1.00
CBEAM       1002      250        5     1001     1.00     0.00    -1.00
CBEAM       1003      260     1001      140     1.00     0.00    -1.00
$ BLADE 2 CONNECTIONS
CBEAM        200       60       24      200    -1.00     -.00     1.00
CBEAM        201      101      200      201    -1.00     -.00     0.00
CBEAM        202      101      201      202    -1.00     -.00     0.00
CBEAM        203      102      202      203    -1.00     -.00     0.00
CBEAM        204      103      203      204    -1.00     -.00     0.00
CBEAM        205      103      204      205    -1.00     -.00     0.00
CBEAM        206      103      205      206    -1.00     -.00     0.00
CBEAM        207      103      206      207    -1.00     -.00     0.00
CBEAM        208      104      207      208    -1.00     -.00     0.00
CBEAM        209      105      208      209    -1.00     -.00     0.00
CBEAM        210      106      209      210    -1.00     -.00     0.00
CBEAM        211      106      210      211    -1.00     -.00     0.00
CBEAM        212      106      211      212    -1.00     -.00     0.00
CBEAM        213      106      212      213    -1.00     -.00     0.00
CBEAM        214      106      213      214    -1.00     -.00     0.00
CBEAM        215      107      214      215    -1.00     -.00     0.00
CBEAM        216      108      215      216    -1.00     -.00     0.00
CBEAM        217      109      216      217    -1.00     -.00     0.00
CBEAM        218      109      217      218    -1.00     -.00     0.00
CBEAM        219      109      218      219    -1.00     -.00     0.00
CBEAM        220      109      219      220    -1.00     -.00     0.00
CBEAM        221      109      220      221    -1.00     -.00     0.00
CBEAM        222      109      221      222    -1.00     -.00     0.00
CBEAM        223      109      222      223    -1.00     -.00     0.00
CBEAM        224      109      223      224    -1.00     -.00     0.00
CBEAM        225      109      224      225    -1.00     -.00     0.00
CBEAM        226      109      225      226    -1.00     -.00     0.00
CBEAM        227      108      226      227    -1.00     -.00     0.00
CBEAM        228      107      227      228    -1.00     -.00     0.00
CBEAM        229      106      228      229    -1.00     -.00     0.00
CBEAM        230      106      229      230    -1.00     -.00     0.00
CBEAM        231      106      230      231    -1.00     -.00     0.00
CBEAM        232      106      231      232    -1.00     -.00     0.00
CBEAM        233      106      232      233    -1.00     -.00     0.00
CBEAM        234      105      233      234    -1.00     -.00     0.00
CBEAM        235      104      234      235    -1.00     -.00     0.00
CBEAM        236      103      235      236    -1.00     -.00     0.00
CBEAM        237      103      236      237    -1.00     -.00     0.00
CBEAM        238      103      237      238    -1.00     -.00     0.00
CBEAM        239      103      238      239    -1.00     -.00     0.00
CBEAM        240      102      239      240    -1.00     -.00     0.00
CBEAM        241      101      240      241    -1.00     -.00     0.00
CBEAM        242      101      241      242    -1.00     -.00     0.00
CBEAM        243       60      242        4    -1.00     -.00     1.00
$ BLADE 2 STRUTS
CBEAM       2000      250       23     2000    -1.00     -.00     1.00
CBEAM       2001      260     2000      202    -1.00     -.00     1.00
CBEAM       2002      250        5     2001    -1.00     -.00    -1.00
```

```
CBEAM      2003      260     2001      240    -1.00      -.00    -1.00
$ LOWER RESTRAINTS
GRID      15000            1.000    0.000    0.000             123456
CELAS2    10000.300E+07        1        1    15000        1
CELAS2    10001.300E+07        1        2    15000        2
CELAS2    10002.200E+08        1        6    15000        6
CDAMP2     9000   1.0E07       1        6    15000        6
$ UPPER RESTRAINTS
GRID      15003                           1768.98              123456
CELAS2    10003.480E+05       26        1    15003        1
CELAS2    10004.480E+05       26        2    15003        2
$ CONCENTRATED MASSES
CONM2      5000        2          6100.00
CONM2      5001        4         10084.00
CONM2      5002       11          2910.00
CONM2      5003       17          2910.00
CONM2      5004       23          9200.00
CONM2      5005       26         25300.00
CONM2      5006      101           459.00
CONM2      5007      141           856.00
CONM2      5008      201           459.00
CONM2      5009      241           856.00
$
EIGR     21      MGIV                              22                       +BC
+BC      MAX
EIGC,11,HESS,MAX,,,,,,+EIGC1
+EIGC1,0.,10.7,0.,13.2,3.,1,12
$
FORCE,103,  26,0,.320E+06,0.,0.,-1.
GRAV        101           386.40      0.0      0.0     -1.0
LOAD,100,1.,1.,101,1.,102,1.,103
RFORCE      102                     0.625      0.0      0.0      1.0        2
SPC1        200        3        1
$ COLUMN POINTS
GRID          1            0.000    0.000    0.000                3          1.00
GRID          2            0.000    0.000   33.667                           1.00
GRID          3            0.000    0.000   67.333                         120.00
GRID          4            0.000    0.000  101.000
GRID          5            0.000    0.000  151.000
GRID          6            0.000    0.000  234.332
GRID          7            0.000    0.000  317.665
GRID          8            0.000    0.000  400.997
GRID          9            0.000    0.000  484.329
GRID         10            0.000    0.000  567.662
GRID         11            0.000    0.000  650.994
GRID         12            0.000    0.000  734.327
GRID         13            0.000    0.000  817.659
GRID         14            0.000    0.000  900.991
GRID         15            0.000    0.000  984.324
GRID         16            0.000    0.0001067.660
GRID         17            0.000    0.0001150.990
GRID         18            0.000    0.0001234.320
GRID         19            0.000    0.0001317.650
GRID         20            0.000    0.0001400.990
GRID         21            0.000    0.0001484.320
GRID         22            0.000    0.0001567.650
GRID         23            0.000    0.0001650.980
GRID         24            0.000    0.0001700.980
GRID         25            0.000    0.0001734.980                         120.00
GRID         26            0.000    0.0001768.980
$ BLADE 1 POINTS
GRID        100           36.000    0.0001700.980
GRID        101           69.762    0.0001676.000
GRID        102          103.524    0.0001651.010
GRID        103          135.678    0.0001627.220
GRID        104          189.519    0.0001587.380
GRID        105          243.360    0.0001547.540
GRID        106          297.201    0.0001507.700
GRID        107          351.042    0.0001467.860
GRID        108          375.158    0.0001450.020
GRID        109          396.961    0.0001429.410
```

```
GRID         110         431.132   0.0001395.770
GRID         111         463.908   0.0001360.780
GRID         112         495.236   0.0001324.480
GRID         113         525.063   0.0001286.940
GRID         114         553.340   0.0001248.210
GRID         115         570.536   0.0001223.630
GRID         116         584.366   0.0001197.010
GRID         117         611.392   0.0001138.270
GRID         118         632.674   0.0001077.210
GRID         119         648.016   0.0001014.400
GRID         120         657.278   0.000 950.410
GRID         121         660.375   0.000 885.826
GRID         122         656.320   0.000 811.952
GRID         123         644.205   0.000 738.966
GRID         124         624.175   0.000 667.744
GRID         125         596.470   0.000 599.142
GRID         126         561.424   0.000 533.985
GRID         127         545.786   0.000 508.382
GRID         128         526.981   0.000 485.008
GRID         129         496.172   0.000 448.271
GRID         130         463.897   0.000 412.815
GRID         131         430.208   0.000 378.699
GRID         132         395.161   0.000 345.980
GRID         133         358.814   0.000 314.712
GRID         134         335.678   0.000 295.613
GRID         135         310.518   0.000 279.274
GRID         136         267.887   0.000 251.590
GRID         137         225.257   0.000 223.905
GRID         138         182.626   0.000 196.220
GRID         139         139.995   0.000 168.535
GRID         140         106.448   0.000 146.750
GRID         141          71.224   0.000 123.875
GRID         142          36.000   0.000 101.000
$ BLADE 1 STRUTS
GRID        1000          60.000   0.0001650.980
GRID        1001          60.000   0.000 151.000
$ BLADE 2 GRID POINTS
GRID         200         -36.000   -.0001700.980
GRID         201         -69.762   -.0001676.000
GRID         202        -103.524   -.0001651.010
GRID         203        -135.678   -.0001627.220
GRID         204        -189.519   -.0001587.380
GRID         205        -243.360   -.0001547.540
GRID         206        -297.201   -.0001507.700
GRID         207        -351.042   -.0001467.860
GRID         208        -375.158   -.0001450.020
GRID         209        -396.961   -.0001429.410
GRID         210        -431.132   -.0001395.770
GRID         211        -463.908   -.0001360.780
GRID         212        -495.236   -.0001324.480
GRID         213        -525.063   -.0001286.940
GRID         214        -553.340   -.0001248.210
GRID         215        -570.536   -.0001223.630
GRID         216        -584.366   -.0001197.010
GRID         217        -611.392   -.0001138.270
GRID         218        -632.674   -.0001077.210
GRID         219        -648.016   -.0001014.400
GRID         220        -657.278   -.000 950.410
GRID         221        -660.375   -.000 885.826
GRID         222        -656.320   -.000 811.952
GRID         223        -644.205   -.000 738.966
GRID         224        -624.175   -.000 667.744
GRID         225        -596.470   -.000 599.142
GRID         226        -561.424   -.000 533.985
GRID         227        -545.786   -.000 508.382
GRID         228        -526.981   -.000 485.008
GRID         229        -496.172   -.000 448.271
GRID         230        -463.897   -.000 412.815
GRID         231        -430.208   -.000 378.699
GRID         232        -395.161   -.000 345.980
GRID         233        -358.814   -.000 314.712
```

```
GRID         234         -335.678   -.000 295.613
GRID         235         -310.518   -.000 279.274
GRID         236         -267.887   -.000 251.590
GRID         237         -225.257   -.000 223.905
GRID         238         -182.626   -.000 196.220
GRID         239         -139.995   -.000 168.535
GRID         240         -106.448   -.000 146.750
GRID         241          -71.224   -.000 123.875
GRID         242          -36.000   -.000 101.000
$ BLADE 2 STRUTS
GRID        2000          -60.000   -.0001650.980
GRID        2001          -60.000   -.000 151.000
$ MATERIAL PROPERTIES
MAT1           10.290E+08.110E+08        .284E+00
MAT1           20.100E+08.400E+07        .978E-01
$
PBEAM         10        10.352E+03.352E+05.352E+05          .704E+05        +ESP0001
+ESP0001  16.000    0.000 -16.000   0.000   0.000 -16.000   0.000   16.000+PBE1001
+PBE1001    YESA     1.0
PBEAM         20        10.491E+03.240E+06.240E+06          .480E+06        +ESP0002
+ESP0002  32.500    0.000 -32.500   0.000   0.000 -32.500   0.000   32.500+PBE1002
+PBE1002    YESA     1.0
PBEAM         30        20.188E+03.335E+06.335E+06          .670E+06        +ESP0003
+ESP0003  60.000    0.000 -60.000   0.000   0.000 -60.000   0.000   60.000+PBE1003
+PBE1003    YESA     1.0
PBEAM         40        10.491E+03.240E+06.240E+06          .480E+06        +ESP0004
+ESP0004  32.500    0.000 -32.500   0.000   0.000 -32.500   0.000   32.500+PBE1004
+PBE1004    YESA     1.0
PBEAM         50        10.352E+03.352E+05.352E+05          .704E+05        +ESP0005
+ESP0005  16.000    0.000 -16.000   0.000   0.000 -16.000   0.000   16.000+PBE1005
+PBE1005    YESA     1.0
PBEAM         60        10.100E+02.400E+05.800E+05          .400E+05
PBEAM        101        20.200E+03.400E+05.400E+05          .100E+05        +ESP0007
+ESP0007   5.145    0.000  -5.145   0.000   0.000 -22.900   0.000   26.100+PBE1007
+PBE1007    YESA     1.0
PBEAM        102        20.100E+03.100E+04.200E+05          .200E+04   11.30+ESP0008
+ESP0008   5.040    0.000  -5.040   0.000   0.000 -22.500   0.000   25.500+PBE1008
+PBE1008    YESA     1.0
PBEAM        103        20.574E+02.583E+03.945E+04          .143E+04    0.92+ESP0009
+ESP0009   5.040   0.0000  -5.040  00.000   0.000 -26.230   0.000   26.230+PBE1009
+PBE1009    YESA     0.25                                                   +PBE1091
+PBE1091    YESA     0.50                                                   +PBE1092
+PBE1092    YESA     0.75                                                   +PBE1093
+PBE1093    YESA     1.00
PBEAM        104        20.847E+02.884E+03.150E+05          .220E+04    3.81+ESP0010
+ESP0010   5.145    0.000  -5.145   0.000   0.000 -22.400   0.000   26.600+PBE1010
+PBE1010    YESA     1.0
PBEAM        105        20.564E+02.321E+03.732E+04          .830E+03    3.50+ESP0011
+ESP0011   3.870    0.000  -3.870   0.000   0.000 -20.200   0.000   22.800+PBE1011
+PBE1011    YESA     1.0
PBEAM        106        20.327E+02.184E+03.398E+04          .478E+03    0.82+ESP0012
+ESP0012   3.780    0.000  -3.780   0.000   0.000 -22.250  -0.188   22.250+PBE1012
+PBE1012    YESA     0.25                                                   +PBE1121
+PBE1121    YESA     0.40                                                   +PBE1122
+PBE1122    YESA     0.75                                                   +PBE1123
+PBE1123    YESA     1.00
PBEAM        107        20.564E+02.321E+03.732E+04          .830E+03    2.65+ESP0013
+ESP0013   3.870    0.000  -3.870   0.000   0.000 -20.200   0.000   22.800+PBE1013
+PBE1013    YESA     1.0
PBEAM        108        20.462E+02.195E+03.446E+04          .509E+03    2.17+ESP0014
+ESP0014   3.330    0.000  -3.330   0.000   0.000 -17.400   0.000   19.600+PBE1014
+PBE1014    YESA     1.0
PBEAM        109        20.260E+02.112E+03.236E+04          .296E+03    0.44+ESP0015
+ESP0015   3.240    0.00   -3.240    0.00   0.000 -19.020  0.0000   19.020+PBE1015
+PBE1015    YESA     0.5                                                    +PBE1151
+PBE1151    YESA     1.0
PBEAM        250        10.100E+02.252E+06.504E+06          .252E+06
PBEAM        260        10.450E+02.200E+04.200E+05          .200E+04        +ESP0026
+ESP0026   1.050    0.000  -1.050   0.000   0.000 -21.000   0.000   21.000+PBE1026
+PBE1026    YESA     1.0
$ MASTER DEGREES OF FREEDOM FOR EIGENVALUE EXTRACTION
```

```
$ASET1,12,5,9,14,19,23,26
$ASET1,123,108,115,121,127,134
$ASET1,123,208,215,221,227,234
$
$ZSET 102 104 106 108 111 113 115 118 120 122 124 127 129 131 134 136 138 140
$$ZSET 102 105 108 111 115 118 121 124 127 131 134 137 140
$$ZSET 120 121 122
$PARAM   GRDPNT  0
$AER      1.15E-7    2.00
PARAM   WTMASS  .002588
PARAM   MAXRATIO 9.E12
$PARAM,LMODES,22
$PARAM,DDRMM,-1
$PARAM,G,0.04
$PARAM,MODACC,+1
$  ROTATING FRAME EFFECTS
$
PARAM   OMEGA     3.5600
DMI     SKEW           0       1       1       0               6       6
DMI     SKEW           2       1   -1.00
DMI     SKEW           1       2    1.00
DMI     SYM            0       6       1       0               6       6
DMI     SYM            1       1    1.00
DMI     SYM            2       2    1.00
DMIG    SOFTNING       0       1       3       0
DMIG    SOFTNING       4       1               4       1  .1E-09
DMIG    CORIOL         0       1       3       0
DMIG    CORIOL         4       1               4       2  .1E-09
DMIG    CORIOL         4       2               4       1  .1E-09
ENDDATA
```

APPENDIX B

Sample Solution 3 Input

```
NASTRAN
ID SNL34, RPM00
TIME 10
SOL 3
COMPILE SOL3,SOUIN=MSCSOU,NOLIST,NOREF
CEND
ECHO=UNSORT
TITLE=SNL34 SOL03 TEST
METHOD=21
DISP(PUNCH)=ALL
BEGIN BULK
.
.
.
put bulk data deck here
.
.
/EOR
```

APPENDIX C

Sample Solution 64 and 71 Input

Solution 64

```
NASTRAN
ID HPVAWT, RPM40
TIME 10
SOL 64
COMPILE SOL64,SOUIN=MSCOU,NOLST,NOREF
CEND
ECHO=UNSORT
TITLE=SNL34 SOL64 TEST
SUBCASE 1
SUBCASE 2
SUBCASE 3
SUBCASE 4
SET 300=4,7,10,12,102,105,110,115,120,125,215
SET 400=2,7,101,105,106,116,125,131
SET 500=2,7,10,101,105,106
DIST=300
FORCE=400
STRESS=500
BEGIN BULK
.
.
put bulk data deck here.
.
.
/EOR
```

NOTE: This solution must be run in conjunction with solution 71 so that the data base is transferred from one to the other.

Solution 71

```
NASTRAN
ASSIGN UNIT=11
ID SNLTB,TEST
TIME 10
SOL71
DIAG 64
COMPILE SOL71,SOUIN=MSCSOU,NOLIST,NOREF
ALTER 1087
MATMOD     SYM,SIL,,,,/SYMG,/5        $PLACE BASIC SYM 6*6 IN G*G MATRIX
MPYAD      MGG,SYMG,/KGSYM//-1     $MPLY MGG BY -SYMG
PARAMR     //'MPY'/S,N,OMEGASQ/V,Y,OMEGA/V,Y,OMEGA  $OMEGASQ=OMEGA2
PARAMR     //'COMPLEX'//S,N,OMEGASQ/0.0/V,N,COMEGASQ  $COMEGASQ=OMEGASQ,0.0
ADD        KGSYM,K2PP/KSOFT/COMEGASQ  $KSOFT=KGSYM*W} +K2GG
$MODTRL     KSOFT////6/  $
EQUIV      KSOFT,K2PP/ALWAYS
MATMOD     SKEW,SIL,,,,/SKEWG,/5       $PLACE BASIC SKEW 6*6 IN G*G MATRIX
MPYAD      MGG,SKEWG,/MGSKEW        $MPLY MGG BY SKEWG
PARAMR     //'MPY'/S,N,OMEGA2/V,Y,OMEGA/2.0    $OMEGA2=2*OMEGA
PARAMR     //'COMPLEX'//V,N,OMEGA2/0.0/S,N,COMEGA2 $COMEGA2=(OMEGA2,0.0)
ADD        MGSKEW,B2PP/CORIOLIS/COMEGA2  $CORIOLIS=COMEGA2*MGSKEW+K2PP
EQUIV      CORIOLIS,B2PP/ALWAYS    $
$ ALTER FOR PH-REVISION
ALTER 1134
```

```
$ NOTE THAT KHH ETC. MAY NOT NECESSARILY BE DIAGONAL.
GKAM       USETD,PHIA,MI,LAMA,DIT,,,,CASESS/MUHH,BUHH,KUHH,PHIDUH/
           NOUE/LMODES/LFREQ/HFREQ/
           -1/-1/-1/V,N,NUH1/V,N,NUH2 $
ADD        KUHH,MUHH/OMEGSQ///2 $
DIAGONAL   OMEGSQ/OMEG/COLUMN/0.5 $
ADD        OMEG,/FHMOD/0.159155 $
MATPRN     FHMOD// $
PURGE      MUHH,BUHH,KUHH,PHIDUH/ALWAYS $
$ RE-DEFINE MATRIX PH.
PARAML     FOL//'TRAILER'/1/S,N,NFQ $
PRTPARM    ///'NFQ' $
PARAML     PHF//'TRAILER'/1/S,N,NCPHF $
PARAML     PHF//'TRAILER'/2/S,N,NMOD $
PARAM      //DIV/V,N,NCASE/NCPHF/NFQ $
PRTPARM    ///C,N,NCASE $ NCASE NOT USED ANYWHERE.
TYPE       PARM,,I,NFQT  $
   NFQT=NFQ*2  $
MATGEN     ,/PUB/4/NMOD/NCPHF/0/NFQT/NCPHF/1/NFQT/NMOD $
ADD        PUB,/PUBDUP/ $
ADD        PUB,PUBDUP/PUC///2 $  REPLACE COL. NO. WITH UNITY.
$ SECOND-LEVEL SEPARATION WITH DMI-HSUP DE-ACTIVATES SPECIFIED
$ MODAL CONTRIBUTIONS. IT COMPLEMENTS LMODES,LFREQ AND HFREQ.
$ AND, IT OBVIATES NEED TO CHANGE SUBCASES AND RANDPS.
PARAML     HSUP//'PRES'////S,N,HFLAG $
EQUIV      PUC,PUC1/HFLAG $
COND       LHS1,HFLAG $
MATGEN     ,/HONE/4/1/NMOD/1/NMOD/NMOD/1/1/1 $
ADD        HONE,HSUP/HSEL//(-1.,0.) $
$ PRINT FREQUENCIES AFTER SECOND-LEVEL SEPARATION VIA HSUP.
PARTN      FHMOD,,HSEL/FDROP,FKEEP,,/1 $
MATPRN     FKEEP,FDROP// $
MATMOD     HSEL,,,,,/HSELD,/28 $
MPYAD      PUC,HSELD,/PUC1/ $
LABEL      LHS1 $
TRNSP      PUC1/PHFNEW/ $
MODTRL     PHFNEW/////3 $ CHANGE TO COMPLEX.
EQUIV      PHFNEW,PHF/ALWAYS $
$MATPRN     PHF// $
ALTER 1135
COND       LHS2,HFLAG $
MPYAD      HSELD,UHVF,/UHVFNEW/ $
EQUIV      UHVFNEW,UHVF/ALWAYS $
LABEL      LHS2 $
$ ALTER FOR ROUTING FREQ. RESP. TO TAPE49.
ALTER 1143
PARAM      //STSR/V,N,OPU/2 $
PARAM      //STSR/C,Y,TPU=49/-2 $
ALTER 1144
PARAM      //STSR/OPU/-2 $
ALTER 1323
PARAM      //STSR/V,N,OPU/2 $
PARAM      //STSR/C,Y,TPU=49/-2 $
ALTER 1324,1324
PARAM      //STSR/OPU/-2 $
$ ALTER FOR PRINTING MODAL PSD-OUTPUT.
$/READ,S30SDP
CEND
ECH0=UNSORT
TITLE=SNL34 TEST
SET 10=0
SEALL=10  $ INCLUDE WHEN SOL 71 RUN SEPARATELY
$SELG=10
$SELR=10
$SEKR=10
$SEMR=10
METHOD = 21
$SDAMP = 101   $ INCLUDE WHEN MODAL DAMPING IS TO BE ADDED
FREQ=101
DLOAD=99  $ DUMMY LOAD
RANDOM=101
```

```
K2PP=SOFTNING
B2PP=CORIOL
OUTPUT
SET 8=2001
SET 9=7,101,104,106,107,111,115,120,124,125,127,130
$SDISP(SORT2,PHASE) = ALL
$DISP(SORT2,PHASE) = 7
ELFO(SORT2,PHASE) = 8
ELSTRESS(SORT2,PHASE) = 9
$ THE NO OF SUBCASES MUST BE 2 TIMES THE NO OF MODES REQUESTED
$   ON THE LMODES CARD
SUBCASE 1
SUBCASE 2
SUBCASE 3
SUBCASE 4
SUBCASE 5
SUBCASE 6
SUBCASE 7
SUBCASE 8
SUBCASE 9
SUBCASE 10
$SUBCASE 11
$SUBCASE 12
$SUBCASE 13
$SUBCASE 14
$SUBCASE 15
$SUBCASE 16
$SUBCASE 17
$SUBCASE 18
$SUBCASE 19
$SUBCASE 20
$SUBCASE 21
$SUBCASE 22
OUTPUT(XYOUT)
XTITLE = FREQUENCY (HERTZ)
 YTITLE = PSD OF FORCE IN UPPER RESTRAINT
XYPRINT ELFO PSDF / 2001(2)
 YTIT = PSD OF STRESS IN ELEMENT 101 AT END A;C,D,E,F
XYPRINT STRESS PSDF / 101(4),101(5),101(6),101(7)
 YTIT = PSD OF STRESS IN ELEMENT 104 AT END B;C,D,E,F
XYPRINT STRESS PSDF / 104(104),104(105),104(106),104(107)
 YTIT = PSD OF STRESS IN ELEMENT 106 AT END A; C D E F
XYPRINT STRESS PSDF / 106(4),106(5),106(6),106(7)
 YTIT = PSD OF STRESS IN ELEMENT 107 AT END A; C,D,E,F
XYPRINT STRESS PSDF / 107(4),107(5),107(6),107(7)
 YTIT = PSD OF STRESS IN ELEMENT 111 AT END A ;C,D,E,F
XYPRINT STRESS PSDF / 111(4),111(5),111(6),111(7)
 YTIT = PSD OF STRESS IN ELEMENT 115 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 115(104),115(105),115(106),115(107)
 YTIT = PSD OF STRESS IN ELEMENT 120 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 120(104),120(105),120(106),120(107)
 YTIT = PSD OF STRESS IN ELEMENT 124 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 124(104),124(105),124(106),124(107)
YTIT = PSD OF STRESS IN ELEMENT 125 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 125(104),125(105),125(106),125(107)
 YTIT = PSD OF STRESS IN ELEMENT 127 AT END A; C,D,E,F
XYPRINT STRESS PSDF / 127(4),127(5),127(6),127(7)
 YTIT = PSD OF STRESS IN ELEMENT 130 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 130(104),130(105),130(106),130(107)
 YTIT = PSD OF STRESS IN ELEMENT 7 AT C,E
XYPRINT STRESS PSDF / 7(4),7(6)
$TITLE=37.5/45 137.5/110 BULK DATA M6T235A W/ AER+AIR //OMG=2.0
BEGIN BULK
.
.
```

insert bulk data deck using ASET and LMODES cards.

```
.
.
ENDDATA
```

APPENDIX D

Sample TRES1.OUT File

```
$
$ DE-ACTIVATE UNWANTED MODES
$
DMI      HSUP          0       2       1       0               3       1
DMI      HSUP          1      18     1.0      19     1.0       3       1
$
$ DEFINITION OF DUMMY LOAD
$
RLOAD1         99      99                     99
DAREA          99       2       1     .00
TABLED1        99                                                      +TABD100
+TABD100       .0     1.0   100.0     1.0    ENDT
$
$ FREQUENCY RESPONSE RANGE
$
FREQ1         101  .00000  .15625      12
$
$   MODAL DAMPING
$
TABDMP1       101    CRIT                                              +TAB1000
+TAB1000     .000    .000    .000    .000    .000    .000    ENDT
$
$ DEFINITION OF DISCRETE PSDS
$
RANDPS        101       1       1     1.0            1001
TABRND1      1001                                                      +TAB1001
+TAB1001     .000 .3395+7    .156 .3305+5    .313 .3811+5    .469 .8285+5+TAB1002
+TAB1002     .625 .1835+7    .781 .6795+5    .938 .2060+5   1.094 .7657+5+TAB1003
+TAB1003    1.250 .1771+7   1.406 .5855+5   1.563 .1282+5   1.719 .7934+4+TAB1004
+TAB1004    1.875 .4773+4    ENDT
RANDPS        101       2       2     1.0            1002
TABRND1      1002                                                      +TAB1005
+TAB1005     .000 .4768+5    .156 .1775+6    .313 .1077+7    .469 .9947+6+TAB1006
+TAB1006     .625 .2009+6    .781 .1230+6    .938 .2735+6   1.094 .3671+6+TAB1007
+TAB1007    1.250 .1450+6   1.406 .7834+5   1.563 .1042+6   1.719 .8901+5+TAB1008
+TAB1008    1.875 .6198+6    ENDT
RANDPS        101       1       1     1.0            1001
TABRND1      1003                                                      +TAB1009
+TAB1009     .000 .1050+5    .156 .3876+6    .313 .2846+6    .469 .2799+6+TAB1010
+TAB1010     .625 .1285+7    .781 .4825+6    .938 .1727+6   1.094 .4455+6+TAB1011
+TAB1011    1.250 .9533+6   1.406 .4496+6   1.563 .1165+6   1.719 .9378+5+TAB1012
+TAB1012    1.875 .9934+4    ENDT
ECHOON
$
$ DEFINITION OF (UPPER TRIANGLE) CROSS SPECTRAL DENSITIES
$
RANDPS        101       1       2     1.0            1004
TABRND1      1004                                                      +TAB1013
+TAB1013     .000 .1006+6    .156 .5502+6    .313 .0000+0    .469 .1980+5+TAB1014
+TAB1014     .625 .0000+0    .781 .6795+5    .938 .6111+5   1.094 .9237+5+TAB1015
+TAB1015    1.250 .8622+4   1.406 .0000+0   1.719 .0000+0   1.875 .1190+4+TAB1016
+TAB1016     ENDT
RANDPS        101       1       2    -1.0            1005
TABRND1      1005                                                      +TAB1017
+TAB1017     .000 .0000+0    .156 .0000+0    .313 .9273+5    .469 .3022+5+TAB1018
+TAB1018     .625 .4535+5    .781 .0000+0    .938 .1994+5   1.094 .8733+4+TAB1019
+TAB1019    1.406 .0000+0   1.719 .6782+4   1.875 .0000+0    ENDT
RANDPS        101       1       2             1.0    1006
TABRND1      1006                                                      +TAB1020
+TAB1020     .000 .4127+5    .156 .3305+5    .313 .0000+0    .938 .0000+0+TAB1021
+TAB1021    1.094 .3327+5   1.250 .1891+6   1.406 .5855+5   1.563 .1671+5+TAB1022
+TAB1022    1.875 .9031+4    ENDT
```

```
RANDPS       101       1       2              -1.0     1007
TABRND1     1007                                                  +TAB1023
+TAB1023    .000 .0000+0    .156 .0000+0      .313 .3811+5      .469 .8285+6+TAB1024
+TAB1024    .625 .1007+6    .781 .6319+5      .938 .2992+5     1.250 .0000+0+TAB1025
+TAB1025   1.406 .7294+5   1.563 .8934+4     1.719 .9023+4     1.875 .0000+0+TAB1026
+TAB1026    ENDT
RANDPS       101       1       3       1.0             1008
TABRND1     1008                                                  +TAB1027
+TAB1027    .000 .0000+0    .156 .0000+0      .313 .7255+4      .469 .0000+0+TAB1028
+TAB1028    .625 .0000+0    .781 .6795+5      .938 .3819+5     1.094 .1440+5+TAB1029
+TAB1029   1.406 .0000+0   1.563 .5931+4     1.719 .9995+4     1.875 .8289+4+TAB1030
+TAB1030    ENDT
RANDPS       101       1       3      -1.0             1009
TABRND1     1009                                                  +TAB1031
+TAB1031    .000 .4059+6    .156 .2004+5      .313 .7022+4      .469 .7466+5+TAB1032
+TAB1032    .625 .0000+0    .781 .0000+0      .938 .4448+5     1.094 .0000+0+TAB1033
+TAB1033   1.719 .0000+0   1.875 .6437+4      ENDT
RANDPS       101       1       3               1.0     1010
TABRND1     1010                                                  +TAB1034
+TAB1034    .000 .0000+0    .156 .3661+5      .313 .5989+4      .469 .5539+5+TAB1035
+TAB1035    .625 .3581+4    .781 .6795+5      .938 .1169+5     1.094 .4880+4+TAB1036
+TAB1036    ENDT
RANDPS       101       2       3       1.0             1011
TABRND1     1011                                                  +TAB1037
+TAB1037    .000 .1954+5    .156 .3453+5      .313 .1138+5      .469 .5485+4+TAB1038
+TAB1038    .625 .1835+6    .781 .4211+4      .938 .7770+5     1.875 .0000+0+TAB1039
+TAB1039    ENDT
RANDPS       101       2       3      -1.0             1012
TABRND1     1012                                                  +TAB1040
+TAB1040    .000 .0000+0    .156 .5043+5      .313 .1238+6      .469 .0000+0+TAB1041
+TAB1041    .625 .0000+0    .781 .7390+5      .938 .5522+5     1.094 .2948+5+TAB1042
+TAB1042   1.250 .0000+0   1.406 .0000+0     1.563 .1539+5     1.719 .2563+4+TAB1043
+TAB1043   1.875 .4948+4    ENDT
RANDPS       101       2       3               1.0     1013
TABRND1     1013                                                  +TAB1044
+TAB1044    .000 .9351+4    .156 .0000+0      .313 .0000+0      .469 .8523+6+TAB1045
+TAB1045    .625 .1004+5    .781 .8388+4      .938 .7829+5     1.094 .7441+5+TAB1046
+TAB1046   1.250 .0000+0   1.406 .2391+5     1.563 .1928+4     1.719 .0000+0+TAB1047
+TAB1047   1.875 .3000+4    ENDT
RANDPS       101       2       3              -1.0     1014
TABRND1     1014                                                  +TAB1048
+TAB1048    .000 .0000+0    .156 .0000+0      .313 .9841+5      .469 .0000+0+TAB1049
+TAB1049    .625 .1046+6    .781 .0000+0      .938 .2338+5     1.094 .7657+5+TAB1050
+TAB1050   1.250 .0000+0   1.406 .5209+5     1.563 .6682+4     1.875 .2333+4+TAB1051
+TAB1051    ENDT
```

APPENDIX E

Sample Airfoil Data File

```
SNLA1850 MOD LAMINAR SECTION (EPPLER)  NOV '83. REC'D NOV 85 AT INDAL
 5000000.0      12.0       0.0       .18
      0.00     0.0000     0.0051
      2.00     0.2200     0.0051
      4.00     0.4400     0.0053
      6.00     0.6139     0.0101
      8.00     0.7759     0.0119
     10.00     0.9100     0.0300
     12.00     0.9600     0.0760
     14.00     0.8400     0.1570
     16.00     0.6000     0.2100
     18.00     0.5200     0.2360
     20.00     0.5600     0.2600
     30.12     0.9398     0.6068
     40.14     1.0868     0.9670
     50.09     1.0608     1.2920
     60.13     0.9229     1.5822
     70.04     0.6914     1.7982
     80.00     0.4062     1.9443
     89.97     0.0863     1.9963
    100.08    -0.2441     1.9650
    110.02    -0.5483     1.8529
    119.95    -0.8055     1.6579
    129.95    -0.8570     1.2985
    139.94    -0.9015     0.9876
    149.90    -0.7438     0.6093
    159.99    -0.4656     0.2835
    169.95    -0.5747     0.0774
    180.00     0.0083     0.0151
SNLA1850 MOD LAMINAR SECTION (EPPLER)  NOV '83. REC'D NOV 85 AT INDAL
 10000000.0     12.0       0.0       .18
      0.00     0.0000     0.0047
      2.00     0.2200     0.0049
      4.00     0.4400     0.0063
      6.00     0.6580     0.0090
      8.00     0.8122     0.0106
     10.00     0.9400     0.0300
     12.00     1.0000     0.0760
     14.00     0.8800     0.1570
     16.00     0.6700     0.2100
     18.00     0.5700     0.2360
     20.00     0.6000     0.2600
     26.00     0.8099     0.4400
     30.12     0.9398     0.6068
     40.14     1.0868     0.9670
     50.09     1.0608     1.2920
     60.13     0.9229     1.5822
     70.04     0.6914     1.7982
     80.00     0.4062     1.9443
     89.97     0.0863     1.9963
    100.08    -0.2441     1.9650
    110.02    -0.5483     1.8529
    119.95    -0.8055     1.6579
    129.95    -0.8570     1.2985
    139.94    -0.9015     0.9876
    149.90    -0.7438     0.6093
    159.99    -0.4656     0.2835
    169.95    -0.5747     0.0774
    180.00     0.0083     0.0151
```

APPENDIX F

Sample Basic Input File (for 34m Test Bed)

```
$ TRESL.DAT supplies basic data for turbulent response of SNL 34
$   for use with TRES4E
$ HT     DIA     HMR     RPM    VBAR    WSE   DELT    ARHO in free format
1780.0 1320.0 1134.0  37.5  45.0  0.16  0.24  0.0766
$
$ C1X  C2X    C1Y    C2Y    Z0    DECAY  VAR NSOFT FMIN  CMIN  in free format
11.87 1928  4.00  70.0  .001  7.50  0.30   1   0.10  4.E1
$
$ TURBULENCE SPECTRUM TYPE # free format
1
$
$ NHT,NDIA,NEIG,NT,NREV,NSECT,NLOOP,NPMAX,NDIV,NOUT,NSUP in free format
  1   1    3    8  4     9    2      3     4   1     2
$
$ INCLUDE DYNAMIC STALL? "YES" OR "NO ", A3 FORMAT
YES
$ INCLUDE COLUMN LOADING? "YES" OR "NO ", A3 FORMAT
YES
$ USE A REDUCED ZSET OF BLADE NODES?
YES
$ select option (1,2,or 3) for printing of cross spectra (free format)
1
$ NSECT(I,TYPE(I), CH(I)) in  format (I4,A8,F10.2)
   1NACA0021  48.0
   2NACA0021  48.0
   3NACA0021  48.0
   4NACA0021  48.0
   5SNLA1850  42.0
   6SNLA1850  42.0
   7SNLA1850  42.0
   8SNLA1850  36.0
   9SNLA1850  36.0
$ eigenvalue numbers and associated critical damping factors, free format
$ default value=.00 If no input, enter one dummy line, then end with "$"
2,0.00
$
$ list of eigenvectors to be suppressed (one to a line, free format)
  18
  19
$ end
.
```

APPENDIX G

Sample Basic Input File for AEROB5.FOR

```
$ AEROBSL.DAT data for SNL 34M ROTOR  . AEROB program.
$   RPM    ARHO    FLUT  AB   CMIN  NSECT (free format)
   37.5  0.0766  4.0  -.2   0.1     9
$ rotational terms included? (A3 format)
YES
$ apparent mass terms included? (A3 format)
NO
$ ZSET used? "YES/NO" free format
YES
$   I  ,TYPE(I), CH(I) in  format (I4,A8,F10.2)
   1NACA0021 48.0
   2NACA0021 48.0
   3NACA0021 48.0
   4NACA0021 48.0
   5SNLA1850 42.0
   6SNLA1850 42.0
   7SNLA1850 42.0
   8SNLA1850 36.0
   9SNLA1850 36.0
..
```

DISTRIBUTION:

R. E. Akins
Washington & Lee University
P.O. Box 735
Lexington, VA 24450

M. Anderson
Renewable Energy Systems, Ltd.
Eaton Court, Maylands Avenue
Hemel Hempstead
Herts HP2 7DR
ENGLAND

M. P. Ansell
School of Material Science
University of Bath
Claverton Down
Bath BA2 7AY
Avon
ENGLAND

H. Ashley
Dept. of Aeronautics and
Astronautics Mechanical Engr.
Stanford University
Stanford, CA 94305

Earl Ausman
Polarconsort Alaska
1503 W. 33rd Avenue
Suite 310
Anchorage, AK 99530

K. Bergey
University of Oklahoma
Aero Engineering Department
Norman, OK 73069

J. Beurskens
Programme Manager for
Renewable Energies
Netherlands Energy Research
Foundation ECN
Westerduinweg 3
P.O. Box 1
1755 ZG Petten (NH)
THE NETHERLANDS

J. R. Birk
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

N. Butler
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

C. P. Butterfield
NREL
1617 Cole Boulevard
Golden CO 80401

R. N. Clark
USDA
Agricultural Research Service
Bushland, TX 79012

C. Coleman
Northern Power Systems
Box 659
Moretown, VT 05660

O. de Vries
National Aerospace Laboratory
Anthony Fokkerweg 2
Amsterdam 1017
THE NETHERLANDS

E. A. DeMeo
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

J. B. Dragt
Institute for Wind Energy
Faculty of Civil Engineering
Delft University of Technology
Stevinweg 1
2628 CN Delft
THE NETHERLANDS

O. Dyes
Wind/Hydro/Ocean Div.
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

A. J. Eggers, Jr.
RANN, Inc.
260 Sheridan Ave., Suite 414
Palo Alto, CA 94306

D. M. Eggleston
DME Engineering
P.O. Box 5907
Midland, TX 79704-5907

A. F. Abdel Azim El-Sayed
Dept. of Mechanical Design &
Power Engineering
Zagazig University
3 El-lais Street
Zeitun
Cairo 11321
EGYPT

J. Ereaux
PR No. 5
Bolton, Ontario L7E 5S1
CANADA

R. A. Galbraith
Dept. of Aerospace Engineering
James Watt Building
University of Glasgow
Glasgow G12 8QG
SCOTLAND

A. D. Garrad
Garrad Hasson
9-11 Saint Stephen Street
Bristol BS1 1EE
ENGLAND

P. R. Goldman
Wind/Hydro/Ocean Division
U.S. Department of Energy
1000 Independence Avenue
Washington, DC 20585

I. J. Graham
Dept. of Mechanical Engineering
Southern University
P.O. Box 9445
Baton Rouge, LA 70813-9445

G. Gregorek
Aeronautical & Astronautical
Dept.
Ohio State University
2300 West Case Road
Columbus, OH 43220

N. D. Ham
Aero/Astro Dept.
Massachusetts Institute of
Technology
77 Massachusetts Avenue
Cambridge, MA 02139

L. Helling
Librarian
National Atomic Museum
Albuquerque, NM 87185

T. Hillesland
Pacific Gas and Electric Co.
3400 Crow Canyon Road
San Ramon, CA 94583

E. N. Hinrichsen
Power Technologies, Inc.
P.O. Box 1058
Schenectady, NY 12301-1058

S. Hock
Wind Energy Program
NREL
1617 Cole Boulevard
Boulder, CO 80401

W. E. Holley
U.S. WindPower
6952 Preston Avenue
Livermore, CA 94550

M. A. Ilyan
Pacific Gas and Electric Co.
3400 Crow Canyon Road
San Ramon, CA 94583

K. Jackson
Dynamic Design
123 C Street
Davis, CA 95616

O. Krauss
Division of Engineering Research
Michigan State University
East Lansing, MI 48825

V. Lacey
Indal Technologies, Inc.
3570 Hawkestone Road
Mississauga, Ontario L5C 2V8
CANADA

A. Laneville
Faculty of Applied Science
University of Sherbrooke
Sherbrooke, Quebec J1K 2R1
CANADA

G. G. Leigh
New Mexico Engineering
Research Institute
Campus P.O. Box 25
Albuquerque, NM 87131

L. K. Liljegren
1916 Pepper Drive
Altadena CA 9100-3523

R. R. Loose, Director
Wind/Hydro/Ocean Division
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

R. Lynette
R. Lynette & Assoc., Inc.
15042 NE 40th Street
Suite 206
Redmond, WA 98052

P. H. Madsen
Riso National Laboratory
Postbox 49
DK-4000 Roskilde
DENMARK

D. Malcolm (10)
R. Lynette & Associates, Inc.
15042 N.E. 40th Street, Suite 206
Redmond, WA 98052

J. F. Mandell
Montana State University
302 Cableigh Hall
Bozeman, MT 59717

B. Masse
Institut de Recherche d'Hydro-Quebec
1800, Montee Ste-Julie
Varennes, Quebec J3X 1S1
CANADA

G. McNerney
U.S. Windpower, Inc.
6952 Preston Avenue
Livermore, CA 94550

R. N. Meroney
Dept. of Civil Engineering
Colorado State University
Fort Collins, CO 80521

D. Morrison
New Mexico Engineering
Research Institute
Campus P.O. Box 25
Albuquerque, NM 87131

V. Nelson
Department of Physics
West Texas State University
P.O. Box 248
Canyon, TX 79016

G. Nix
NREL
1617 Cole Boulevard
Golden, CO 80401

J. W. Oler
Mechanical Engineering Dept.
Texas Tech University
P.O. Box 4289
Lubbock, TX 79409

D. I. Page
Energy Technology Support Unit
B 156.7 Harwell Laboratory
Oxfordshire, OX11 ORA
ENGLAND

C. Paquette
The American Wind Energy Association
777 N. Capitol Street, NE
Suite 805
Washington, DC 20002

I. Paraschivoiu
Dept. of Mechanical Engineering
Ecole Polytecnique
CP 6079
Succursale A
Montreal, Quebec H3C 3A7
CANADA

T. F. Pedersen
Riso National Laboratory
Postbox 49
DK-4000 Roskilde
DENMARK

H. Petersen
Riso National Laboratory
Postbox 49
DK-4000 Roskilde
DENMARK

R. G. Rajagopalan
Aerospace Engineering Department
Iowa State University
404 Town Engineering Bldg.
Ames, IA 50011

R. Rangi
Manager, Wind Technology
Dept. of Energy, Mines and Resources
580 Booth 7th Floor
Ottawa, Ontario K1A 0E4
CANADA

M. G. Real, President
Alpha Real Ag
Feldeggstrasse 89
CH 8008 Zurich
SWITZERLAND

R. L. Scheffler
Research and Development Dept.
Room 497
Southern California Edison
P.O. Box 800
Rosemead, CA 91770

L. Schienbein
Battelle-Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

T. Schweizer
Princeton Economic Research, Inc.
12300 Twinbrook Parkway
Suite 650
Rockville, MD 20852

D. Sharpe
Dept. of Aeronautical Engineering
Queen Mary College
Mile End Road
London, E1 4NS
ENGLAND

J. Sladky, Jr.
Kinetics Group, Inc.
P.O. Box 1071
Mercer Island, WA 98040

M. Snyder
Aero Engineering Department
Wichita State University
Wichita, KS 67208

L. H. Soderholm
Agricultural Engineering
Room 213
Iowa State University
Ames, IA 50010

W. J. Steeley
Pacific Gas and Electric Co.
3400 Crow Canyon Road
San Ramon, CA 94583

F. S. Stoddard
Second Wind, Inc.
7 Davis Square
Somerville, MA 02144

D. Taylor
Alternative Energy Group
Walton Hall
Open University
Milton Keynes MK7 6AA
UNITED KINGDOM

G. P. Tennyson
DOE/AL/ETD
Albuquerque, NM 87115

W. V. Thompson
410 Ericwood Court
Manteca, CA 95336

R. W. Thresher
NREL
1617 Cole Boulevard
Golden, CO 80401

K. J. Touryan
3701 Hawkins Street, NE
Albuquerque, NM 87109-4512

W. A. Vachon
W. A. Vachon & Associates
P.O. Box 149
Manchester, MA 01944

P. Vittecoq
Faculty of Applied Science
University of Sherbrooke
Sherbrooke, Quebec J1K 2R1
CANADA

T. Watson
Canadian Standards Association
178 Rexdale Boulevard
Rexdale, Ontario M9W 1R3
CANADA

L. Wendell
Battelle-Pacific Northwest
Laboratory
P.O. Box 999
Richland, WA 99352

W. Wentz
Aero Engineering Department
Wichita State University
Wichita, KS 67208

R. E. Wilson
Mechanical Engineering Dept.
Oregon State University
Corvallis, OR 97331

M. Zuteck
MDZ Consulting
931 Grove Street
Kemah, TX 77565

M.S. 0100	Document Processing (10) For DOE/OSTI
M.S. 0167	J. C. Clausen
M.S. 0437	E. D. Reedy
M.S. 0439	C. Dohrmann
M.S. 0439	D. W. Lobitz
M.S. 0439	D. R. Martinez
M.S. 0443	J. G. Arguello
M.S. 0443	H. S. Morgan
M.S. 0447	G. H. James III
M.S. 0447	J. P. Lauffer
M.S. 0557	T. J. Baca
M.S. 0557	T. G. Carne
M.S. 0557	P. S. Veers
M.S. 0619	Technical Publications
M.S. 0708	H. M. Dodd (20)
M.S. 0708	T. D. Ashwill
M.S. 0708	D. E. Berg
M.S. 0708	D. P. Burwinkle
M.S. 0708	M. A. Rumsey
M.S. 0708	L. L. Schluter
M.S. 0708	H. J. Sutherland
M.S. 0827	G. F. Homicz
M.S. 0833	J. H. Strickland
M.S. 0899	Technical Library (5)
M.S. 9018	Central Technical Files